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Yan, Ying; Dittmann, Lars

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Modeling and Simulation of Handover Scheme in Integrated EPON-WiMAX Networks

Ying Yan and Lars Dittmann

Department of Photonics Engineering, Technical University of Denmark
Kgs. Lyngby, Denmark
E-mail: {yiya, ladit}@fotonik.dtu.dk

Abstract

In this paper, we tackle the seamless handover problem in integrated optical wireless networks. Our model applies for the convergence network of EPON and WiMAX and a mobility-aware signaling protocol is proposed. The proposed handover scheme, Integrated Mobility Management Scheme (IMMS), is assisted by enhancing the traditional MPCP signaling protocol, which cooperatively collects mobility information from the front-end wireless network and makes centralized bandwidth allocation decisions in the backhaul optical network. The integrated network architecture and the joint handover scheme are simulated using OPNET modeler. Results show validation of the protocol, i.e., integrated handover scheme gains better network performances.

1. Introduction

During recent years the number of mobile users has grown rapidly. The emerging multimedia services have driven up bandwidth requirements and motivated research of integration and convergence of optical networks and wireless networks.

In the optical regime, Ethernet Passive Optical Network (EPON) has received a worldwide deployment to provide FTTx (x stands for home, building, curb, etc.), because of the bandwidth enhancement and lower maintenance cost offered by optical fibres. In the wireless regime, various wireless access technologies have been developed with an intention to satisfy the continuously growing demand for ubiquitous communication. World Interoperability for Microwave Access (WiMAX) can support diverse communication capabilities for both fixed and mobile users. In the integrated network architecture, the wireline network (EPON) is used to interconnect multiple wireless networks (WiMAX).

Integrated control platform is an important and challenging design issue in the integrated EPON-WiMAX network. In order to ensure an efficient usage of both optical link and radio spectrum, coordinated control could be applied for the overall integrated architecture. In this sense, the roaming among multiple wireless networks, which are the front-end in the integrated network architecture, requires support and assistance from the traditional EPON network. The performance of integrated EPON and WiMAX is studied by designing the traditional and proposed model and conducting discrete event simulations of the models.

There are many studies about handover schemes in wireless networks to provide a fast and seamless roaming. As suggested in previous work, one approach to addressing the mobility issue

is to reduce the scanning delay (e.g. channel measurement delay) by either using an efficient scheduling scheme [1] or reducing the number of scanning channels [2]. Another approach focuses on improving handover procedures.

A cross layer handover mechanism is derived in [3]. The combinations of the MAC layer and the network layer messages are utilized to reduce the signaling overhead. The work in [4] aims specifically to improve the handover performances for real-time applications by using a connection ID assignment strategy. Additionally, there are research about joint mobility and network control design, for example, optimal power and handover control design [5] and cell mobility based admission control design [6].

In this paper, a coordinated handover scheme is proposed by enhancing the signaling protocol and the resource allocation scheme in EPON, so that mobility performances in terms of latency and disrupting time are improved in multiple WiMAX networks. The rest of the paper is organized as follows. Section 2 presents the integrated EPON and WiMAX network model. Network design and OPNET simulation are introduced in Section 3. Section 4 describes our proposed mobility aware bandwidth allocation scheme. In section 5 the performance results are analyzed.

2. System Model

We consider the integrated architecture with EPON as the backbone network and a WiMAX network with multiple cells as the frond-end network (as shown in Figure 1).

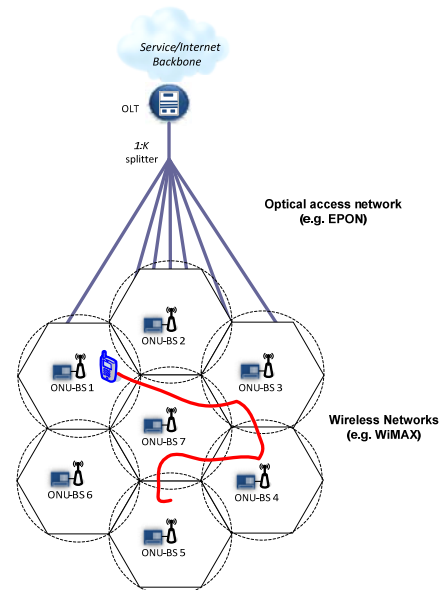


Figure 1: Integrated EPON and WiMAX network architecture

A typical EPON system consists of one Optical Line Terminal (OLT) functionalized as a central office, one passive optical splitter implemented in the remote node, and multiple Optical Network Units (ONUs) residing at subscribers' locations. The front-end wireless network consists of a set of k cells $\{k = 1, 2, \dots, K\}$ of and a set of m Mobile Users (MSs) $\{m = 1, 2, \dots, M\}$ in each cell. The service area is partitioned so that each client connects to only one cell at any given time. The handover occurs when a MS travels among cells.

2.1 EPON Signaling Control

In the optical domain, the transmission between the OLT and multiple ONUs is based on a poll/grant mechanism. The signaling access protocol in the EPON MAC layer is known as the MultiPoint Control Protocol (MPCP) [7]. MPCP is designed only for the EPON network. There is no mobility concern. In the downstream direction from the OLT to the associated ONUs, data are broadcasted to each ONU in a point-to-multipoint fashion. On the other hand, it is a multipoint-to-point fashion in the upstream direction from the ONUs to the OLT. The OLT allocates upstream bandwidth among the ONUs and each ONU transmits packets in dedicated time slots. The OLT commands and the ONU information are exchanged by two types of MPCP messages: REPORT message is used by an ONU to report bandwidth requirements (normally this value is based on queue occupancies) to the OLT; GATE message is transmitted by the OLT to issue transmission grants to each ONU. The upstream network resource can be distributed among ONUs using either fixed bandwidth allocation algorithms or Dynamic Bandwidth Allocation (DBA) algorithms [8].

2.2 WiMAX Mobility

In the wireless domain, WiMAX mobility is based on the IEEE 802.16e standard [9]. In this paper, the hard handover scheme is adopted. The handoff procedure consists of several major stages: network topology acquisition and advertisement, cell scanning, handover decision and initiation, synchronization to the target BS, ranging, and network re-entry.

2.3 Proposed Integrated Mobility Management Scheme (IMMS)

The proposed Integrated Mobility Management Scheme (IMMS) utilizes an enhanced MPCP signalling protocol to assist the handover scheme. In order to cooperate with mobility control, the traditional MPCP is extended and new fields are added into the GATE and REPORT signalling messages. We define the control messages deployed in IMMS as *GATE-m* and *REPORT-m*. The *GATE-m* and *REPORT-m* message convey the handover signalling messages and data packets between the OLT and the ONU-BS.

As illustrated in Figure 2, the proposed Integrated Mobility Management Scheme (IMMS) is implemented in the integrated EPON-WiMAX network architecture. When MS moves out of its serving area, a handover to the neighbouring BS is performed to maintain its service connections.

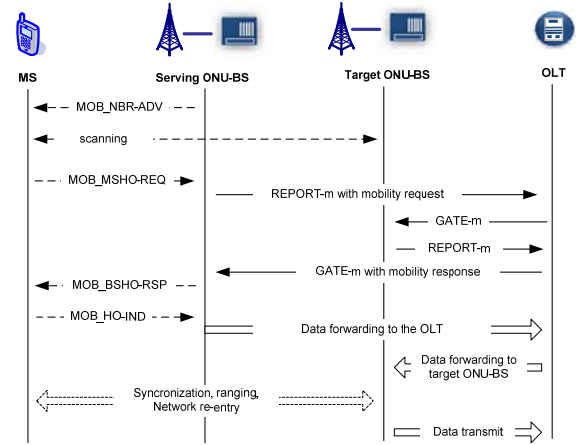


Figure 2: Integrated Mobility Management Scheme (IMMS)

Regarding to the mobility support, the traditional MPCP in EPON has both pros and cons. In the downstream direction, the broadcast ability is of benefit to distribute data to both the serving ONU-BS and the target ONU-BS. When the intention of mobility is reported to the OLT, the data for the MS will be transmitted to both the serving and the target ONU-BS at the same time, which reduces the signalling latency and the packet loss rate during the handover process.

In the upstream direction, ONU-BSs are polled by the OLT in turns and assigned the upstream transmission periods. In the integrated network architecture, multiple ONU-BSs connect to the OLT with no communication among the ONUs. The received mobility control messages and data have to be queued in the OLT and the target ONU-BS until the serving ONU-BS is polled. The traditional poll/request/grant mechanism affects the handover process with additional polling delay. The residue data and the new data after handover are queued until the ONU-BS receives the bandwidth grant from the OLT. Moreover, the polling sequence decides the polling delay, which is the interval between two successive polls to an ONU.

In our proposed IMMS, the signalling scheme is modified to reduce the polling latency, and the additional upstream bandwidth is assigned to provide fast data transmission tunnel for mobile users. We propose new bandwidth allocation schemes in the EPON to provide a fast data transmission tunnel for mobile users. A fixed or dynamic amount of bandwidth, aiming to transmit data for mobile users, is granted to each ONU-BS in addition to the request/grant normal bandwidth.

3. OPNET Integrated EPON-WiMAX Simulator

We have developed an integrated EPON-WiMAX model in OPNET (shown in Figure 3). Our system extensively simulates all the essential entities of the network such as OLT, ONU-BS, Network Controller etc. We have considered most of the functionalities at all the protocol layers. In the following sections, we briefly describe the relevant functional blocks of our model implementation. Proposed handover schemes are implemented including mobility and the resource allocation

algorithm.

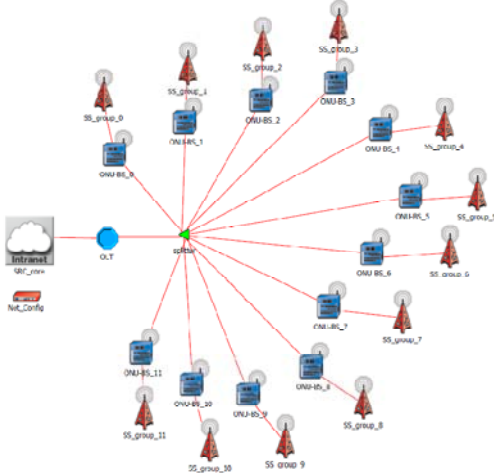


Figure 3: OPNET Integrated EPON-WiMAX Network

3.1 Handover Scheme at ONU-BS

The ONU-BS node is responsible for communications with both the OLT and the MS. Figure 4 shows the basic functionalities including receiving GATE control message (the *rx_ga* state), transmit REPORT message (*gen_UL* state), communication with MS (*rx_ss* and *tx_DL* state), handover operations (*cell_up* state).

To commence the handover the MS sends mobility-action-intension messages to the serving BS. The MS acquires information about the target network either by receiving network advertisements from the serving BS or scanning of neighbour BSs. In the current IEEE 802.16e specification, the BS can obtain information of neighbouring BSs from the network and periodically broadcasts this information to the MS using a MOB_NBR-ADV message. The MS determines the target BS according to the received network parameters, such as Received Signal Strength Indicator (RSSI) and channel error rate.

A sequence of handover messages are communicated between the serving BS, the target BS and the MS. To establish communication the MS needs to synchronize with the downlink channel of the target BS. The target BS will send the DL/UL MAP to the MS to specify the UL/DL transmission opportunity. The target BS can obtain the MS information from the serving BS through the backbone network. For handover service, the MS performs network re-entry process including reauthorization and re-registration. Afterwards the MS continues with the connection to the target ONU-BSs. Data is received and queued in the target ONU-BS. When the target ONU-BS is polled and assigned with the upstream transmission bandwidth, data is sent.

3.2 Mobility Aware Signalling Mechanism at OLT

Figure 5 shows the OLT process model. The OLT polls ONU-BSs and issues transmission grants to them in a round-robin fashion. Only the polled ONU-BS can transmit in the uplink. The residue data in the serving ONU-BS is transferred to the OLT during the granted time slots.

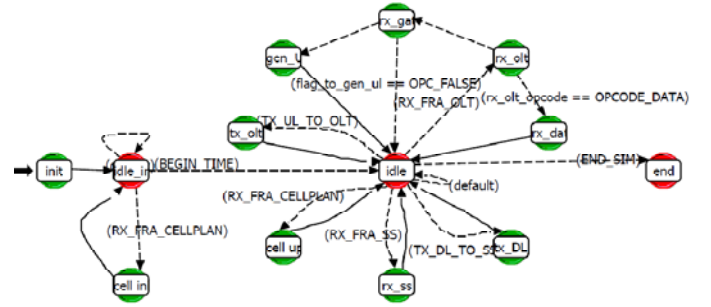


Figure 4: ONU-BS process model

The handover process contains two parts: the exchange of control messages and the relay of data. Due to the centralized control in EPON, both parts of handover procedures are mediated by the OLT. Using the GATE-m message, granted bandwidth and start time are assigned (in state *gate_sche*). ONU-BSs are polled in sequence based on the scheduling policy used in the OLT. In this example, ONU-BSs are polled in an increased order of their LLID number using Round Robin (RR) scheduling. The following IMMS procedures are carried out.

In EPON, the OLT learns the overall network information via the REPORT message, which are collected from all connected ONU-BS (in *rx_report* state). By taking advantage of the central control, the OLT disseminates this information to each ONU-BS and assists MSs with the selection of the optimal target ONU-BS. For example, traffic load can be jointly considered during making a decision.

4. Enhanced Bandwidth Allocation Scheme

The OLT communicates with ONU-BSs via the GATE and the REPORT messages. Upstream bandwidth is allocated to each ONU-BS to relay data packets. During the handover process, new bandwidth needs to be requested, after the MS moves its connection from the serving ONU-BS 1 to the target ONU-BS *k*.

4.1 Bandwidth Allocation Problem Statement

The bandwidth allocation for the upstream transmission is illustrated in Figure 6. At t_0 , MS sends the mobility intension to ONU-BS 1, which relays the handover request to the OLT via Report₁ message at t_1 . When the OLT polls the ONU-BS *k*, the mobility request message is embedded and transmitted with the Gate_k message at t_2 . The response from the target ONU-BS *k* is forwarded back to ONU-BS 1, when ONU-BS 1 is polled again after a polling cycle ($T_{\text{polling}} = t_3 - t_0$). The *polling cycle* is the interval between two successive polls to an ONU-BS. During a polling cycle, all connected ONU-BSs are polled and finished their transmission with the OLT. The length of a polling cycle is determined by the total number of ONU-BSs and their granted transmission periods. If the handover intension is accepted, the residue data (d_{ul-res}) in the serving ONU-BS 1 needs to be transferred to the target ONU-BS *k*. However, the data cannot be sent to the OLT immediately. The serving ONU-BS 1 should

Using the traditional MPCP, it is noted that a complete data transmission experiences additional handover delay, which is caused by the polling procedures in EPON. The polling cycle ($T_{polling}$) is calculated as the sum of all granted bandwidth (BW^j) to K ONU-BSs (illustrated in Eq (1)). R_o is the transmission rate of the optical uplink and T_g is the guard time between two successive upstream data.

The values of delay to transmit the residue data (D_{res}) and the new arrival data (D_{new}) are calculated in Eq (2) and Eq (3).

$$D_{new} = t_7 - t_5 = T_{polling} + (t_6 - t_5) \quad (3)$$

4.2 Fixed Mobile Bandwidth Grant (FMBG) scheme

```

graph LR
    init((init)) -- "(BEGIN_TIME)" --> gate_sch((gate_sch))
    gate_sch -- "(TX_GATE_MSG)" --> idle((idle))
    gate_br((gate_br)) -- "(TX_DATA_MSG)" --> idle
    data_br((data_br)) -- "(RPT_GATE_MSG)" --> idle
    tx_report((tx_report)) -- "(END_SIM)" --> end((end))
    tx_sacData((tx_sacData)) -- "(SOURCE_PKT_ARR)" --> idle
    tx_report -- "(REPORT_PKT_ARR)" --> idle
    idle -- "(default)" --> idle
    init -- "" --> tx_sacData
  
```

Figure 5: OLT process model

$$D_{new} = t_6 - t_5 \quad (6)$$

4.3 Dynamic Mobile Bandwidth Grant (DMBG) scheme

After the response from the target ONU-BS is returned (at t_2), the OLT assigns an approximate amount of the upstream bandwidth to the target ONU-BS, which is aimed to transmit data for the new connected mobile users. The value of bandwidth is an estimation based on the previous transmission of mobile users and provided by the serving ONU-BS. When the re-registration with the new cell is completed at t_5 , the target ONU-BS will receive additional bandwidth and new arrival data can be uploaded at t_6 . The handover delay is reduced, because the polling period for new connected MS is eliminated.

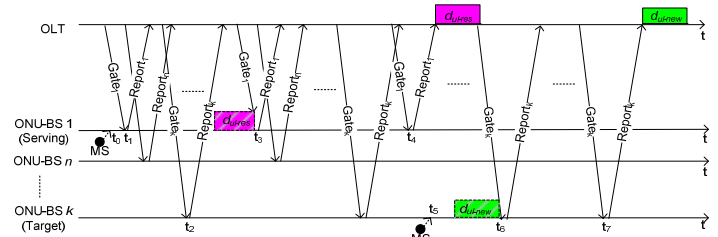


Figure 6: Traditional MPCP with handover data transmission

Compared to the traditional scheme, the dedicated bandwidth is

assigned to the serving and the target ONU-BS in order to reduce the handover latency. Compared to the FMBG scheme, the additional bandwidth is allocated only to the cell with mobility intension, which eliminates the delay for all ONU-BS. However, information (such as buffered data size) is required from the serving ONU-BS, which results in complex control and more overhead. The value of polling cycle changes when there is additional bandwidth granted for the handover process.

5. Performance Evaluation

We simulated the integrated mobility scheme in the integrated EPON and WiMAX network architecture using OPNET [10]. Network topology is shown in Figure 1. The simulation parameters are shown in Table 1 and Table 2. Traffic arrival process follows a Poisson distribution and the mean arrival rate varies from 0.01 to 0.1 Mbps per MS. For simplicity there is one ONU-BS per wireless cell and MSs are distributed randomly over the cell region.

Table 1. System Parameters of Simulation in EPON

Parameters	Value
Number of ONUs in the EPON	16 or 32
Power saving options	PIS and EMM
Optical uplink bandwidth allocation	Fixed and DBA
Downstream traffic profile	Poisson process
Optical link rate (uplink and downlink)	1 Gbps
Guard time	5 μ s
MPCP control message overhead	280 bits
Maximum upstream bandwidth assignment for each ONU	2 Mbits

Table 2. A summary of WiMAX System parameters

Parameters	Value
System	TDMA
Frequency band	3.5 GHz
System bandwidth	10 MHz
Propagation model	Erc g model; Propagation environment type C: flat terrain with light tree densities.
BS power	+40 dBm
fading st. dev.	8 dB
BS antenna gain	+ 17 dBi
SS antenna gain	0 dBi
BS antenna height	35 m above ground
SS antenna height	2 m above ground
Noise power	-138.41 dBm
Noise figure	7 dB
Mobile users	Up to 100 MSs

Figure 6 shows the handover latency at different traffic loads. The handover delay is defined as the interval between the mobility intension sent from the MS and the communication setup to the target ONU-BS. The handover latency is reduced by eliminating the polling delay when traffic load is low. The delay increases because of the cumulated queued data and request bandwidth from each ONU-BS when traffic load is high. The DMBG scheme outperforms the other schemes because it removes the additional bandwidth, which increase the polling cycle.

Figure 7 shows the FMBG experiences longer delay when the

number of ONU-BSs becomes higher. When more ONU-BSs involved, the polling cycle becomes longer and the queued delay increases when traffic load becomes high.

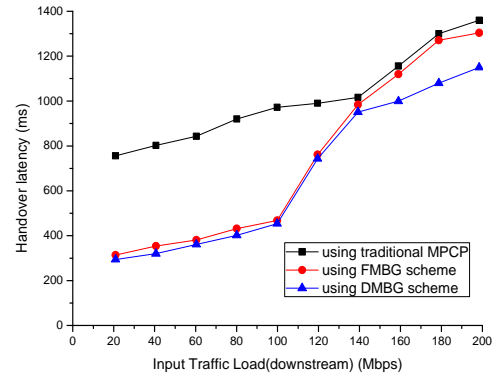


Figure 6: Traditional MPCP with handover data transmission Performance results: handover latency vs. traffic load;

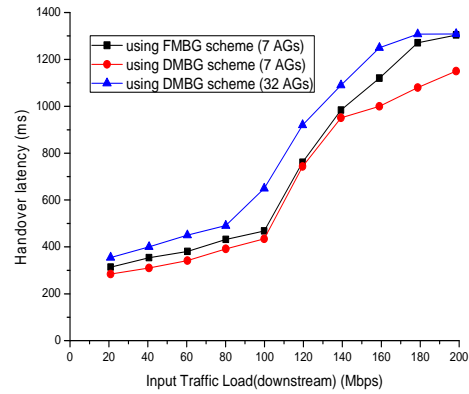


Figure 6: Traditional MPCP with handover data transmission Performance results: handover latency under different number of ONU-BSs.

6. Conclusion

In the integrated EPON and WiMAX network, a seamless handover and Quality of Service (QoS) provision is an important issue. In this work, we analyze the problem in supporting the handover process and propose two enhanced scheme. The scheme can avoid the additional polling delay caused in the optical domain. The integrated network architecture and functionalities are modelled in OPNET. Extensive simulations are carried out based on different traffic profiles. By performance evaluation, we show that the proposed scheme can reduce the handover latency.

7. Acknowledge

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